# The positioning stability tests with the fixed inter-system biases on the Multi-GNSS kinematic PPP

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## Abstract

This paper presents an analysis of positioning stability in the Precise Point Positioning (PPP) method using data from the multi-GNSS constellations (GPS, GLONASS, Galileo and BeiDou). The difference between navigation satellite systems induces the inter-system biases (ISBs). GNSS data processing has to consider various ISBs such as GPS-GLONASS, GPS-Galileo, and GPS-BeiDou. These biases can be estimated as key parameters in the multi-GNSS PPP processing. We develop a unified method with the fixed ISBs for multi-GNSS PPP, where ISBs do not need to be considered. To verify our model, we perform multi-GNSS kinematic PPP under the elevation angle constraints of GNSS satellite. Comparing to traditional combined PPP solution, our method shows more stable positioning results at higher elevation angle constraints.

## Multi-GNSS PPP strategy and Results

We performed multi-GNSS PPP using different navigation signals received at DAEJ reference station in South Korea. The data processing strategy and model for multi-GNSS PPP are listed in Table 1. A comprehensive analysis, including satellite visibility, dilution of precision, position accuracy is performed to evaluate multi-GNSS PPP in constrained elevation angle of satellites.

Table 1. Strategy and model for multi-GNSS precise positioning.

| Item | Models |
|---|---|
| Estimator | Extended Kalman Filter (mode: kinematic) |
| Observations | Undifferenced phase and code observations |
| Signals | GPS: L1/L2, GLO: L1/L2, BDS: B1/B2, GAL: E1/E5a |
| Sampling rate | 30s |
| Elevation cutoff | 7 degree |
| Satellite orbit and clock | GFZ products |
| Mapping Function | GMF/GPT2 |
| Satellite-Receiver APC | Corrected using IGS08 atx. |
| Inter-system biases | Estimated |
| Terrestrial frame | ITRF2008 |
| Phase ambiguities | Float solutions |

· Test 1: Satellite constraints with 30 degree elevation angle

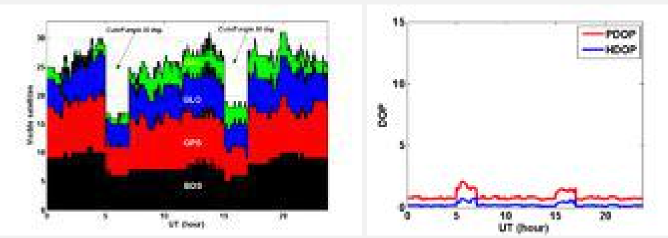


Figure 1. (Left image) The visibility of BDS, GPS, GLO and GAL satellites received at DAEJ station in South Korea on May 1, 2016. For tests of the positioning stability, the cutoff angles of satellite at two different sections (5-7 UT and 15-17 UT) were changed with 30 degrees. The number of visible satellites was also sharply decreased at two sections. The right image shows DOP values for combined four system modes at DAEJ during that day. Nevertheless a average number of the visible satellites at two sections dropped over almost 10, large-scale changes in DOP variations were not seen.

Traditional PPP | Unified PPP

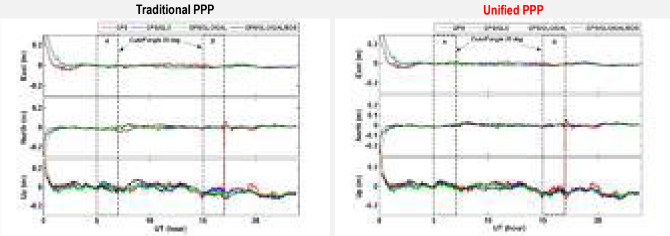

Figure 2 shows the results of the kinematic PPP solutions with different processing modes, GPS only, GPS+GLO, GPS+GLO+GAL, and GPS+GLO+GAL+BDS respectively. The traditional PPP solutions are shown in the left image. At two different sections (A and B), it can be seen that the positioning accuracy in all processing modes was not reduced in spite of the drop of visible satellites. The right image shows the positioning errors derived from the unified PPP approach. A key issue of this method is to consider ISB values which are estimated in kinematic PPP mode. When the cut-off elevation changes to 30 degrees at sections A and B, different ISB values are fixed as a constant. Therefore, in PPP mode, the four satellite systems are regarded as one-satellite system like the GPS. As shown in the right image, when the cut-off elevation angles changes to 30 degrees momentarily at A and B, the positioning accuracy of few centimeters was obtained continuously. Compared to the traditional PPP method, however, we could not find an advantage of the unified PPP approach with the cut-off elevation angle of 30 degrees.

## Results

· Test 2: Satellite constraints with 50 degree elevation angle

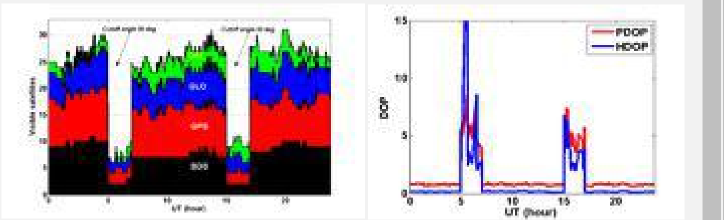


Figure 3. (Left image) The number of visible satellites received at DAEJ station in South Korea on May 1, 2016. The cutoff angles of satellite at two different sections were changed temporarily with 50 degrees. The number of visible satellites was sharply decreased in two sections. (Right image) DOP values sharply increased over 15 with the reduction of visible satellites. Large-scale changes in DOP variations were obviously seen. In particular, DOP value in the first section is greater than that in the 2nd section due to the poor geometry of visible satellites.

Traditional PPP | Unified PPP

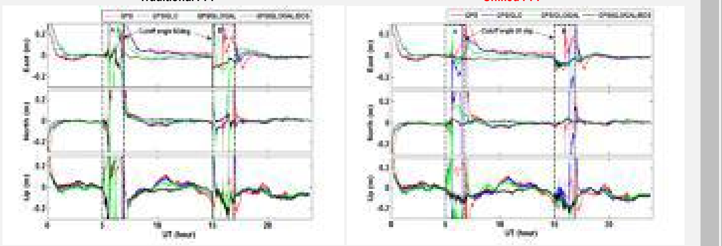

Figure 4 shows the results of the kinematic PPP solutions under the cut-off elevation angles of 50 degrees. The processing modes include GPS only, GPS+GLO, GPS+GLO+GAL, and GPS+GLO+GAL+BDS respectively. The traditional PPP solutions are shown in the left image. At two different sections, A and B, the positioning accuracy decreases dramatically in all processing modes due to poor measurements of GNSS. In particular, when the cut-off elevation angle changes to 50 degrees in sections A and B, it is difficult to maintain a positioning stability with few centimeters. In particular, the positioning accuracy in A is more unstable than that in B. This is originated from the satellite observations. The results on the right images are obtained by the unified PPP approach. It can be obviously seen that the accuracy and reliability of the unified PPP method increases better than those of the traditional PPP method. The unified PPP mode of four (GPS+GLO+GAL+BDS) satellite systems enables us to maintain a positioning accuracy of few centimeters (*plotted in the dark solid line).

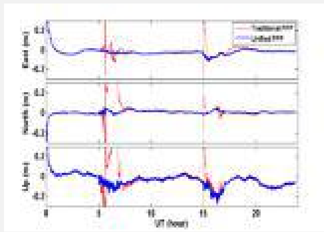

Figure 5 shows the positioning results of the kinematic PPP under the cut-off elevation angles of 50 degrees at two temporary sections with combined satellite systems (GPS+GLO +GAL+BDS). As seen in Figure 5, the positioning accuracy of the unified PPP is much more stable than the traditional PPP.

## Summary and Conclusion

We analyzed the kinematic PPP performance in different multi-system modes under different cut-off elevation angles with 30 and 50 degrees. The position time series of the DAEJ reference station are shown in Figures. 2 and 4. The two different PPP approaches were considered to investigate the positioning stability. By comparing aspects of the positioning stability and reliability, we could suggest that the accuracy and reliability of the traditional PPP decreases dramatically when the cut-off elevation angle changes to 50 degrees in the temporary sections. In higher elevation of 50 degrees, the traditional PPP method cannot provide continuous precise positioning. Whereas the positioning accuracy of the unified PPP was slightly decreased and few centimeter was still achievable even with the cut-off elevation of 50 degrees. Combined multi-GNSS PPP can improve a user's positioning accuracy. Furthermore, the unified PPP approach presented in the present study can increase a positioning stability in urban areas.

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